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Abstract: We analysed the effect of three portion sizes Optocal Plus (small, medium and large) on swallowing thresholds in subjects with either conventional complete dentures or mandibular implant-retained overdentures (transmandibular and permucosal cylindric implants). Tests were carried out in 52 women and 15 men (mean age 59 years) 4 years after treatment in a randomised controlled clinical trial. The results indicated that the degree of mucosal support for the mandibular denture did not affect the number of chewing strokes, time till swallowing or swallowed particle size. Only the chewing rate differed: subjects wearing mandibular implant-retained overdentures chewed the food at a higher rate than complete-denture wearers. With larger portion sizes, subjects needed significantly more chewing strokes and time until swallowing and they would have swallowed larger particles. Men chewed their food more efficiently than women, as they used the same number of chewing strokes and time, but achieved a greater particle size reduction at the swallowing moment.

The ability of complete-denture wearers to comminute foods is dramatically reduced. Their comminution of food during chewing is only one-fourth to one-seventh of that of subjects with natural dentitions and depends on the age of the subjects and the type of food (Kapur & Soman 1964; Heath 1982; Slagter et al. 1993; Fontijn-Tekamp et al. 2000). Subjects with a diminished masticatory performance tend to swallow larger food particles, despite the fact that they chew the food for a larger number of chewing cycles (van der Bilt et al. 1993b). When larger particles are swallowed, this affects gastrointestinal function, as both lag phase and half-emptying time are significantly longer (Pera et al. 2002). There is no evidence in the literature that complete-denture wearers have more gastrointestinal disorders. Obviously, they have developed strategies to avoid problems with chewing by choosing soft and easier-to-chew foods (Chauncey et al. 1984) and by preparing their foods differently.

Subjects with problems wearing complete dentures might benefit from dental implant treatment. After implant treatment, most subjects have fewer complaints, are more satisfied and have a better subjective chewing ability (Geertman et al. 1996; Meijer et al. 1999; Naert et al. 1999; Tang et al. 1999; Bakke et al. 2002). Nevertheless, effects on objective function as evaluated by conducting masticatory performance, chewing efficiency and swallowing threshold tests, as well as bite-force measurements are less obvious. For example, masticatory performance is not improved by the provision dental implants (Haraldson et al. 1988; Garrett et al. 1998), whereas it improved in other studies (Carlsson & Lindquist 1994;

Geertman et al. 1994; Bakke et al. 2002). One study claims that this improvement depends on the degree of implant support for the mandibular denture (Carlsson & Lindquist 1994), while in other studies no such effect is observed (Geertman et al. 1994; Tang et al. 1999). Also, the results for swallowing threshold tests are contradictory. Either a significant decrease in the number of strokes and time till swallowing is observed (Carlsson & Lindquist 1994), or no effect is found (Haraldson et al. 1988). These studies provide no information about the particle size distribution at the swallowing moment as subjects actually swallow the food.

The aim of our study was to evaluate the effect of different mucosal support for the mandibular denture on swallowing thresholds. Furthermore, we studied the effects of repetition, portion size and gender. We hypothesise that subjects with mandibular implant-retained overdentures swallow smaller food particles, as in most studies their masticatory performance (Carlsson & Lindquist 1994; Geertman et al. 1994; Bakke et al. 2002) and bite force (Haraldson et al. 1988; Carlsson & Lindquist 1994; Fontijn-Tekamp et al. 1998; Bakke et al. 2002; van Kampen et al. 2002) are significantly higher than for subjects with conventional complete dentures. We also expect a lower number of chewing cycles to prepare the food for swallowing as subjects with an improved masticatory performance needed less chewing cycles and time before swallowing (van der Bilt et al. 1993b). Measurements were performed in subjects with either conventional complete dentures or mandibular implant-retained overdentures 4 years after denture treatment, as part of a randomised controlled clinical trial.

Material and methods

Subjects

Swallowing-threshold tests have been performed at the 4-year follow-up of a clinical trial, which involved 60 edentulous females and 18 males (mean age 59 years, range 41–77). All participants had been referred by general practitioners to the Special Dental Care Clinic for persistent problems wearing complete dentures. They had been edentulous for an average of 24 years and had severely resorbed mandibles (symphyseal bone height between 8 and 15 mm, Geertman et al. 1994).

All subjects had received new maxillary complete dentures and in the mandible either: (1) a mainly implant-borne overdenture retained by a transmandibular implant according to Bosker (TMI-group, Fig. 1a), (2) an implant–mucosa-borne overdenture retained by two permucosal cylindric IMZ implants (IMZ-group, Fig. 1b) or (3) a mucosa-borne conventional denture (CD-group). In the TMI group, overdentures were attached through five metal clips to a triple (Dolder) bar construction with cantilever extensions and in the IMZ group through one metal clip to a single (Dolder) bar. In all groups, porcelain teeth had been used and posterior teeth were arranged according to the lingualised occlusion concept.

A balancing procedure had been used to allocate treatment in order to enhance the comparability of treatment groups with respect to age, gender and prosthetic history (Geertman et al. 1996). Several subjects were lost to follow-up because of various reasons (Fontijn-Tekamp et al. 1998). So far, 10 complete-denture wearers had been treated with dental implants because of persistent problems. The ethics committee had insisted on providing dental implants if problems had not been solved after 1 year of denture wearing. These 10 subjects were excluded from further analyses. The sample sizes in the treatment groups are given in Table 1. Informed written consent had been obtained from all participants prior to entry into the trial. The ethics committee of the Nijmegen University had given their approval for this trial.

Swallowing-threshold tests

The *swallowing threshold* is defined as the moment that subjects do feel the urge to swallow or normally do swallow their food. Swallowing-threshold tests have been performed using Optocal Plus artificial test food. The test food was prepared by mixing 58.3% by weight Optosil® Plus (Bayer Dental, Leverkusen, Germany, version 1997) with 7.5% toothpaste (Everclean, HEMA BV, Amsterdam, The Netherlands), 11.5% vaseline (Dr Swaab, Boots Healthcare, Hilversum, The Netherlands), 10.2% powder of dental plaster (Super Fix White®, Börgardts GmbH, Walkenried, Germany) and 12.5% alginate powder (Blueprint cremix®, De Trey Dentsply Ltd, Weybridge, England). This putty component was mixed with 20.8 mg/g catalyst paste. Finally, test particles were prepared in moulds and stored in an electrical stove for 16 h at 65°C (Slagter et al. 1992).

The test food was offered in portions of 6, 11 and 17 cubic particles with an edge size of 5.6 mm (approximately 1, 2 and 3 cm^3, respectively). Portions are further referred to as small, medium and large.

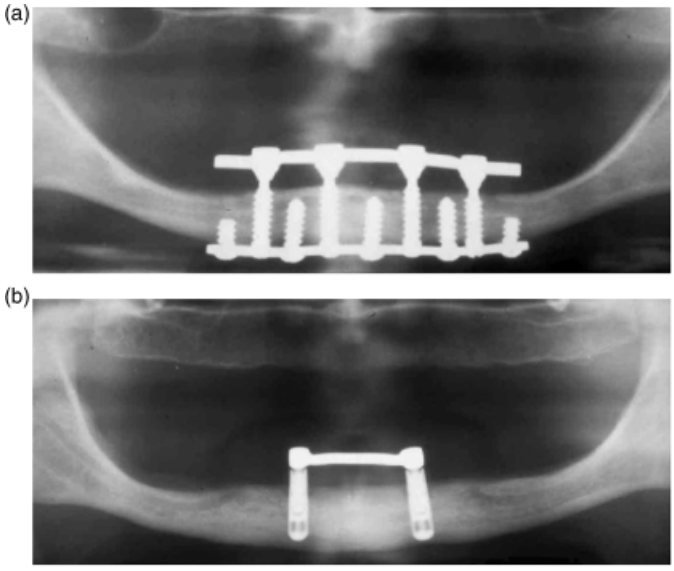

Fig. 1. Orthopantomographic radiographs of (a) a transmandibular implant and (b) two permucosal, cylindric IMZ implants with superstructure.

Table 1. **Number of subjects and treatment groups according to gender**

Treatment groups	4-Year follow-up period			Baseline Total
	Men	Women	Total	
Transmandibular implant	6	18	24	30
Two IMZ implants	5	22	27	29
Complete dentures	4	12	16*	30
Total	15	52	67	89

*Ten complete-denture wearers had received dental-implant treatment between the 1- and 4-year follow-up period.

Subjects were instructed to chew until they felt the desire to swallow and then spit out the particles on a filter paper. Mouth and dentures were carefully rinsed with water and these rinsings were added to the expectorated particles. First, they practised with a medium portion size (spit-out particles from this portion size were not analysed). Then, portions were offered twice in the following order: medium, small and large portions (six study portions in total). The time needed till swallowing was registered as well as the number of chewing strokes utilised.

The collected particles were air dried before sieving. Particles were sieved on a stack up to 12 sieves, with apertures decreasing from 5.6 to 0.5 mm and a bottom plate during 14 min (Laboratory Sieving machine VS1000, F. Kurt Retsch GmbH & Co. KG, Haan, Germany). The amount of test food was weighed for each sieve and for the bottom plate as well as the total amount of collected test food. For each portion, the median particle size (X_{50}) was calculated (Olthoff et al. 1984; van der Bilt et al. 1993a).

Statistical procedures

Statistical analyses were performed on the number of chewing strokes, time till swallowing, chewing rate (number of strokes per minute) and median particle size. Repeated-measures ANOVA with Greenhouse–Geisser as the correction factor was performed to study the effects of treatment (denture type), gender, repetition and portion size. Treatment and gender were included as between-subject factors and repetition and portion size as within-subject factors. *Post hoc* tests were conducted to clarify the differences. Pearson's correlation coefficients were calculated between first and second measurements. $P<0.05$ was considered to be significant.

Results

Effects of denture type

Repeated-measures ANOVA indicated no interactions between treatment, gender, repetition and portion size. No statistical difference was observed in the number of chewing strokes, the time till swallowing and median particle sizes among the three treatment groups (all P-values >0.187, Table 2). However, chewing rates differed ($P=0.05$). *Post hoc* tests revealed that complete-denture wearers chewed their food at a lower rate than the two implant groups.

Effects of gender

The effects of gender were limited. No differences in the number of strokes, time and chewing rate were observed between men and women (all P-values >0.179, Table 2). Only the median particle size (X_{50}) was significantly influenced by gender, i.e. men would have swallowed smaller particles than women (Table 3).

Repetition of measurements

High measurement–remeasurement correlations existed for all swallowing-threshold parameters (i.e. $0.82<r<0.95$). Nevertheless, there was a significant effect of repetition on these parameters (all P-values <0.024, Table 2). There was a shift towards a more careful food processing at the second measurement occasion, including more strokes and more time needed, which results in smaller median particle sizes (see Table 4). Furthermore, subjects chewed the second time at a higher chewing rate.

Effects of portion size

Repeated-measures ANOVA showed a significant effect from portion size on the number of chewing strokes, time till swallowing, chewing rate and median particle size (all P-values <0.048, see Table 2). Subjects needed more strokes and time to chew larger portion sizes of Optocal Plus. They decreased their chewing rate from 85.6 ± 15.8 to 82.7 ± 14.7 strokes/min (whole population). Nevertheless, with larger portions they achieved less particle size reduction before swallowing as demonstrated by higher values of X_{50} (Table 4).

Table 2. **Significance levels of effects on swallowing-threshold parameters**

	Treatment	Gender	Repetition	Portion
Number of strokes	0.751	0.538	0.002	0
Time till swallowing	0.317	0.967	0.024	0
Chewing rate	0.05	0.179	0.004	0.048
Median particle size	0.187	0.01	0.009	0

Repeated-measures ANOVA was carried out with treatment and gender as between-subject factors and repetition and portion size as within-subject factors. Actual outcomes of repeated measures ANOVA were presented. No interactions existed between treatment, gender, repetition and portion size.

Table 3. **Effects of gender, repetition and portion size on median particle sizes**

Gender	Repeat	Portion size		
		Small	Medium	Large
Men	First	2.2 ± 0.94	2.24 ± 1.03	2.34 ± 0.99
	Second	1.98 ± 1.13	2.11 ± 0.88	2.19 ± 0.88
Women	First	2.8 ± 1.14	3.06 ± 1.16	3.12 ± 1.15
	Second	2.69 ± 1.11	2.86 ± 1.19	2.94 ± 1.12

Data are presented as mean $\pm$ SD. There is a significant effect on the median particle size of gender ($P=0.01$), repetition ($P=0.009$) and portion size ($P=0$, see Table 2).

Table 4. **Effect of repetition and portion size on swallowing-threshold parameters**

		Portion size		
		Small	Medium	Large
Number of strokes	First	32.6 ± 17.2	38.1 ± 18.3	45.2 ± 20.5
	Second	34.2 ± 18.6	41.8 ± 21.9	50.6 ± 26
	Difference*	−1.6 ± 7.2	−3.7 ± 10.4	−5.4 ± 10.1
Time till swallowing	First	23.9 ± 14.9	29.2 ± 17	34.3 ± 17.4
	Second	24.5 ± 15	30.6 ± 18.8	37.3 ± 22.2
	Difference	−0.6 ± 4.6	−1.5 ± 7.8	−3 ± 7.8
Chewing rate	First	84.8 ± 16.1	81.8 ± 15.2	81.5 ± 14.8
	Second	86.3 ± 16.4	84.9 ± 15.3	83.9 ± 15.3
	Difference	−1.5 ± 7.4	−3.1 ± 8.6	−2.4 ± 6.3
Median particle size	First	2.67 ± 1.12	2.87 ± 1.18	2.94 ± 1.16
	Second	2.53 ± 1.1	2.69 ± 1.17	2.77 ± 1.11
	Difference	0.1 ± 0.5	0.2 ± 0.7	0.2 ± 0.5

*Difference is expressed as the difference between the first and second measurements.
Data are presented as mean ± SD. There is a significant effect on the four swallowing-threshold parameters of repetition (all *P*-values <0.024) and portion size (all *P*-values <0.048, see Table 2).

Discussion

In this study, swallowing threshold tests were performed with an artificial test food called Optocal Plus. For measurements of masticatory performance and chewing efficiency, artificial test foods are commonly used (Omar et al. 1987; Slagter et al. 1992; van der Bilt et al. 1993b; Buschang et al. 1997). They are preferred to natural foods since physical properties such as size, shape and toughness are more reproducible (Edlund & Lamm 1980; Olthoff et al. 1984). A disadvantage compared with natural food is that subjects are not familiar with actually swallowing artificial test foods. Therefore, it is very important to give subjects clear instructions and practice before starting experiments.

The results of the present study demonstrated that an artificial test food could be used for swallowing threshold tests as subjects did feel the urge to swallow. They even increased their effort for larger portion sizes by higher numbers of chewing strokes and needed more time till swallowing, as expected from other studies with different portion sizes (Lucas & Luke 1984; Buschang et al. 1997).

Although measurement–remeasurement correlations were high, effects of repetition on swallowing threshold parameters were significant. Comparisons between first and second measurements showed a more careful food processing for the second measurement with more chewing strokes and time till swallowing. There might be a learning aspect involved. Normally, it is necessary to repeat measurements in order to produce stability in the data and reduce the variation that normally exists in these types of measurements (Jiffry 1983; Lindquist & Carlsson 1985; Haraldson et al. 1988). However, the results of this study showed no statistical interaction between repetition and the other variables. This meant that both measurements revealed the same effects of treatment, gender and portion size on the swallowing threshold. Thus, in this case one measurement per portion size would have been sufficient to study the effects on the swallowing threshold.

In our study, gender differences were observed for the median particle size. Men would have swallowed smaller particles than women. Men seemed to chew their food more efficiently than women, since both men and women used the same number of chewing strokes and time till swallowing. Although there are many factors that influence chewing efficiency, these men can be expected to chew their food more vigorously, as they exerted significantly higher bite forces than women (Fontijn-Tekamp et al. 1998).

The effects of treatment on swallowing thresholds were rather limited: only chewing rates were different for the three treatment groups. *Post hoc* tests revealed that both implant groups chewed the three portion sizes with a significantly higher frequency than the complete-denture group. For all portion sizes, implant groups had a frequency of about 87 strokes/min, whereas complete-denture wearers reached 75 strokes/min. Similar results were obtained in a within-subject study on masticatory function (Bakke et al. 2002). After implant treatment, subjects had a reduced duration of the chewing cycle (thus a higher chewing frequency) as compared with the results with their unsupported dentures. This difference in frequencies might be caused by retention and stability problems with conventional complete dentures (Fontijn-Tekamp et al. 2001).

No significant effects of treatment were found on the other swallowing threshold parameters, like the number of chewing strokes, time and median particle size. Several studies have demonstrated higher bite forces (Haraldson et al. 1988; Carlsson & Lindquist 1994; Fontijn-Tekamp et al. 1998; Bakke et al. 2002; van Kampen et al. 2002) and better masticatory performance (Carlsson & Lindquist 1994; Geertman et al. 1994; Bakke et al. 2002) after implant treatment. Also, an improved masticatory performance leads to less chewing cycles and time before swallowing (van der Bilt et al. 1993b). Therefore, we had hypothesised that subjects with mandibular implant-retained overdentures would swallow smaller food particles (lower median particle sizes) and needed less chewing cycles and time to prepare the food for swallowing than subjects with conventional complete dentures. We did not observe these differences. Apparently, there is no relationship between how efficient subjects can chew their food (chewing efficiency or masticatory performance) and what they actually swallow (swallowing threshold).

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Résumé

L'effet d'Optocal Plus (petit, moyen et large) a été analysé sur les seuils de déglutition de sujets avec

soit des prothèses complètes conventionnelles soit des prothèses sur implants mandibulaires (implants cylindriques transmuqueux et transmandibulaire). Les tests ont été menés sur 52 femmes et quinze hommes (moyenne d'âge 59 ans) quatre années après le traitement dans un essai clinique contrôlé et randomisé. Les résultats ont indiqué que le degré de support muqueux pour la prothèse mandibulaire n'affectait pas le nombre de mouvements de mastication, le temps avant la déglutition ou la taille de la particule avalée. Seul le taux de mastication différait : les sujets portant une prothèse sur implant mâchaient la nourriture à un taux supérieur aux porteurs de prothèses complètes conventionnelles. Avec des portions plus larges, les sujets nécessitaient significativement plus de mouvements de mastication et de temps jusqu'à la déglutition et ils auraient avalé des particules plus larges. Les hommes mâchaient leur nourriture avec plus d'efficacité que les femmes vu qu'ils utilisaient le même nombre de mouvements de mastication et de temps mais arrivaient à une réduction de taille des particules plus importante au moment de la déglutition.

Zusammenfassung

Grenzwerte beim Schlucken während des Kauens von Portionen mit verschiedenen Grössen mit implantatgetragenen Hybridprothesen im Unterkiefer

Wir analysierten den Einfluss von 3 verschiedenen Portionengrössen Optocal Plus (klein, mittel und gross) auf die Grenzwerte beim Schlucken bei Patienten mit entweder konventionellen Totalprothesen oder implantatgetragenen Hybridprothesen im Unterkiefer (transmandibuläre, transmukosale Zylinderimplantate). Die Untersuchung wurde an 52 Frauen und 15 Männern (mittleres Alter 59 Jahre) 4 Jahre nach Behandlungsabschluss in einer randomisierten kontrollierten klinischen Untersuchung durchgeführt.
Die Resultate zeigen, dass der Grad an mukosaler Auflage der Unterkieferprothese die Anzahl der Kaubewegungen, die Zeit bis zum Schlucken und die Grösse der geschluckten Partikel nicht beeinflusste. Nur die Kaurate unterschied sich: Probanden mit implantatgetragenen Hybridprothesen im UK kauten die Nahrung in höherem Masse als die Totalprothesenträger. Mit zunehmender Portionengrösse benötigten die Probanden signifikant mehr Kaubewegungen und Zeit bis zum Schlucken und sie schluckten grössere Partikel. Männer kauten die Nahrung effizienter als Frauen. Sie benötigten die gleiche Anzahl Kaubewegungen und die gleiche Zeit, aber sie erreichten zum Zeitpunkt des Schluckens eine bessere Reduktion der Partikelgrösse.

Resumen

Hemos analizado el efecto de 3 tallas de porciones de Optocal Plus (pequeña, media y grande) en los umbrales de deglución en sujetos tanto con dentaduras postizas convencionales o sobredentaduras implantosoportadas (implantes cilíndricos transmucosos y permucosos). Se llevaron a cabo pruebas en 52 mujeres y 15 hombres (edad media 59 años) cuatro años tras el tratamiento en un experimento aleatorio clínicamente controlado.
Los resultados indican que el grado de soporte mucoso para la dentadura mandibular no afectó al número de chasquidos de masticación, al tiempo hasta la deglución o al tamaño de la partícula deglutida. Solo el ritmo de masticación difirió: los sujetos portadores de sobredentaduras implantosoportadas masticaron la comida a un ritmo mayor que los usuarios de dentaduras completas. Con tallas de porciones mayores, los sujetos necesitaron más chasquidos de masticación y tiempo hasta deglutir y hubiesen tragado partículas mayores. Los hombres masticaron su comida mas eficientemente que las mujeres, usaron el mismo número de chasquidos masticatorios y de tiempo pero lograron una mayor reducción del tamaño de las partículas en el momento de la deglución.

要旨
我々は、従来の総義歯装着者あるいは下顎インプラント支持オーバーデンチャー（経下顎貫通型及び粘膜貫通型シリンダー・インプラント）装着者において、３つのポーション・サイズ（S、M、L）の **Optocal Plus** が嚥下の閾値に及ぼす影響を分析した。無作為対照付き臨床試験において、女性５２名、男性１５名（平均年令５９才）に、治療後４年後に試験を行った。その結果、下顎義歯の粘膜支持の程度は、咀嚼ストロークの回数、嚥下までの所要時間あるいは嚥下される食片の大きさに影響を及ぼさないことが分かったが、咀嚼率だけが異なっていた；インプラント支持の下顎オーバーデンチャーの装着者は、総義歯装着者よりも効率よく咀嚼した。より大きなポーション・サイズの場合は、被験者の咀嚼回数と嚥下までの所要時間が増え、嚥下された食片のサイズも大きくなったと思われる。男性は女性よりも食物の咀嚼効率がよく、咀嚼回数と嚥下までの時間は同じであったが、食片は嚥下されるまでに、より小さいサイズになっていた。

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